

TABLES OF HEAT CAPACITY AND ENTHALPY OF WATER AND STEAM

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Experiments on the heat capacity of water and steam at various pressures are presented. Comparison is made between results obtained previously under less adequate conditions and those made more recently with improved methods and equipment. Resistance thermometers and thermostat resistance coils were used in the tests. A discussion is given concerning the accuracy of measuring c_p in the critical zone. Various disparities between authors regarding the values in the critical zone are discussed. Tables and equations are provided that illustrate the methods used.



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In the past ten years the All-Union Power Engineering Institute (A.U.P.E.I.) has carried out several series of experiments on the heat capacity c_p of water and steam at pressures from 20 to 500 kg/cm² (kilograms per square centimeter) and at temperatures from 10 to 600 degrees C. (References 1-6). The primary purpose of these experiments was that of rendering more accurate the experimental data which had previously been obtained by other authors using less advanced equipment. Experiments were also carried out on heat capacity in areas which had not previously been studied: at pressures greater than 260 kg/cm² and at temperatures below 200°C, in the vicinity of the saturation curve, and also at pressures less than 150 kg/cm² and at temperatures greater than 450°C. By integrating the experimental data according to c_p and by computing the enthalpy according to the data, it was shown that the improvements which have been made in the last few years in the measuring method of the A.U.P.E.I. (References 1, 3) not only substantially reduced the disparities in the experimental points but also

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resulted in a significant reduction in the systematic errors. It can be stated at the present time that the accuracy of the A.U.P.E.I. data computed according to c_p concerning the significance of enthalpy is in complete agreement with the accuracy of direct measurements of enthalpy made according to the throttle method. Later on, some new results in the graphic-analytical handling of the c_p data by the A.U.P.E.I. are discussed.

The fact that at the present time we have numerous experimental data on c_p makes it possible to construct a table of base points (bases) for the same values of pressure and temperature for which new skeletal tables will be constructed according to the decision of the International Coordinating Committee on Properties of Steam.

Several works are known by which, with the aid of various graphic methods, tables of bases of heat capacity c_p were obtained. In Reference 7 a table of c_p was published. In constructing this table the graphic method was used based on the variables p, V instead of the usual variables p, t . The utilization of a specific volume as one of the variables results in simpler functions of c ; however, along with this it entails additional difficulties: the use of this method depends upon the interpolation of experimental data according to the specific volume. In all probability, this volume precisely explains the fact that the lines of constant heat capacity in the p - t coordinates, constructed according to the data in the table in Reference 7, have sharp breaks for the values of c_p from 2.5 kcal/kg \cdot $^{\circ}\text{C}$ and above. This situation was studied in the following work (Reference 8) in which, after interpolating according to the method presented in Reference 7, the lines of constant heat capacity were drawn into the p - t coordinates, and isobars and isotherms were also drawn in the c_p - t and c_p - p

coordinates. At pressures below 25 kg/cm^2 these diagrams were used directly for processing the experimental data, i.e., the method presented in Reference 7 was not used, probably owing to the difficulty in interpolating the experimental data concerning the specific volume.

In Reference 7 the experimental data of the A.U.P.E.I. were not considered at pressures above 300 kg/cm^2 and in Reference 8 the data which had been published subsequently in Reference 5 and Reference 6 were not studied. The tables of heat capacity in the handbook (Reference 9), which were compiled prior to the conducting of the experiments of the A.U.P.E.I. (References 3-6), had become obsolete to an even greater extent. It should also be recalled, as has already been stated in Reference 5, that not in a single one of the works on constructing c_p tables was any consideration given to the difference between the mean heat capacity which had been measured experimentally and the true heat capacity which must be obtained by introducing into the experimental data corrections which reach significant values in the critical area (Reference 5). For this reason the A.U.P.E.I. carried out new work on constructing tables of c_p bases (Table 1) on the basis of the latest experiments carried out by the A.U.P.E.I. (References 1-6) and also on the basis of the experimental data of Koch on the c_p of steam, which agree satisfactorily with the measurement results of the A.U.P.E.I. (References 1, 6). The measured results of the heat capacity of steam (References 1, 2) were converted in accordance with the new data on the dependence of the c_p of water upon pressure at room temperature published in Reference 11. The new values were 0.1 to 0.3% less than the former values. In constructing Table 1 no special interpolating method of any kind was used, since for small exceptions the experimental material on c_p

is sufficient for constructing tables of bases with the aid of the usual graphic methods, including the critical area (Figure 1).

The accuracy analysis of the experimental data of the A.U.P.E.I. for areas rather remote from the critical point was given in References 1 and 3. The accuracy of the measured results in the critical area (References 5, 6) is determined primarily by the errors in proportion, i.e., the errors in measuring the pressure and temperature to which the measured c_p value in the test relates.

The sum error of proportion is calculated according to the following formula:

$$\Delta c_p = \frac{1}{c_p} \left| \left(\frac{\partial c_p}{\partial p} \right)_t \Delta p + \frac{1}{c_p} \left| \left(\frac{\partial c_p}{\partial t} \right)_p \Delta t \right| \right| \quad (1)$$

where Δp and Δt refer to errors in the measurement of the pressure and temperature.

Immediately after the tests conducted within the pressure interval of 200-230 kg/cm² (References 5, 6), a piston manometer ZH-1000 was employed with a model MP-2500 manometer used for measuring specific volumes in the critical area (Reference 12). The effective cross-section of the piston of this manometer was determined by the All-Union Scientific Research Institute of Metrology (A.U.S.R.I.M.) in Leningrad, to be at an accuracy of 0.01% thus making it possible to consider the pressure measurement accuracy in References 5 and 6 to be 0.02%.¹

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¹As has already been noted in Reference 6, a few errors were made at the time the results of the measurements in Reference 5 were published: the correct values of the pressures at the isobars near the critical pressure were as follows: 224.95 and 229.95 kg/cm², the relative temperature at isobars 229.95, 240 and 275 kg/cm² must be reduced by 0.05°C.

The new value of the constants of the ZH-1000 manometer deviate by 0.03% from the calibrations of the Institute of the Committee of Standards in Moscow of the All-Union Scientific Research Institute Committee (A.U.S.R.I.C.) i.e., it does not exceed the limits of accuracy of these calibrations.¹

It is more difficult to evaluate the accuracy of the temperature measurements.

It was shown in Reference 3 that according to the estimate of the co-workers of the A.U.S.R.I.M., the error in the measurements of temperature made by means of a resistance thermometer, conceived by experts in the Committee of Standards and calibrated in the A.U.S.R.I.C., may reach 0.05°C , in which case a large part of this error is a result of the calibration of the thermometer being done at the boiling point of sulfur. In the last few years the A.U.S.R.I.M. has carried out a large project aimed at making it possible to increase the accuracy of the calibrations in resistance thermometers, in particular instead of calibrations at the boiling point of sulfur the thermometers have been calibrated at the melting point of zinc. As was indicated in Reference 5, after tests had been made in the critical area, the resistance thermometer was calibrated in the A.U.S.R.I.M. A substantial increase in the accuracy of the calibration makes it possible to estimate the error in measuring the temperature in these tests at $0.02 - 0.03^{\circ}\text{C}$.

Thermostat resistance coils were used by the A.U.P.E.I. in measuring the c_p of water and steam. Resistance R_0 was carefully determined over a

¹The calibration of the manometer of this type is being carried out in the A.U.S.R.I.C. by determining the effective cross-section of each of the three pistons separately.

long period of time at the melting point of ice which had been prepared from distilled water. Platinum outlet leads were used for the purpose of reducing the parasitic "T.E.D.S."¹ at the tip of the thermometer. A further increase in accuracy is only possible, in our opinion, by using resistance thermometers which are hermetically sealed and by replacing the calibrations in the melting point of ice (which are quite long and which do not always provide sufficient accuracy) by calibrations in the triple point of water which must be carried out quite often during the measurements. It is also necessary to be certain that the corrections in the indications of the potentiometer have been determined with sufficient accuracy and that their changes during the time between two calibrations of the potentiometer do not affect the accuracy of the measurements. In addition, it is necessary to emphasize once more that the calibrations of the resistance thermometers

TABLE I. Base values of heat capacity c_p in kcal/kg °C.

$t, ^\circ\text{C}$	0	50	100	150	200	250	300	350	375	400	425	450	475	500	550	600
$p, \text{kg/cm}^2$																
75	1.000	0.996	1.004	1.027	1.070	1.159	1.289	1.460	1.672	1.926	2.222	2.561	2.944	3.372	3.846	4.366
76	0.997	0.994	1.003	1.026	1.068	1.157	1.287	1.458	1.670	1.924	2.220	2.559	2.942	3.370	3.844	4.364
100	0.915	0.933	1.001	1.023	1.063	1.143	1.263	1.434	1.646	1.900	2.196	2.535	2.918	3.346	3.820	4.340
125	0.981	0.992	1.000	1.022	1.060	1.136	1.256	1.427	1.639	1.893	2.189	2.528	2.911	3.339	3.813	4.333
150	0.991	0.991	0.993	1.020	1.057	1.130	1.252	1.423	1.635	1.889	2.185	2.524	2.907	3.335	3.809	4.329
175	0.989	0.990	0.998	1.018	1.054	1.127	1.249	1.420	1.632	1.886	2.182	2.521	2.904	3.332	3.806	4.326
200	0.987	0.988	0.996	1.017	1.053	1.126	1.248	1.419	1.631	1.885	2.181	2.520	2.903	3.331	3.805	4.325
225	0.986	0.987	0.995	1.016	1.052	1.125	1.247	1.418	1.630	1.884	2.180	2.519	2.902	3.330	3.804	4.324
250	0.984	0.986	0.994	1.014	1.050	1.124	1.246	1.417	1.629	1.883	2.179	2.518	2.901	3.329	3.803	4.323
275	0.982	0.985	0.993	1.012	1.048	1.123	1.245	1.416	1.628	1.882	2.178	2.517	2.899	3.328	3.802	4.322
300	0.980	0.984	0.992	1.010	1.046	1.122	1.244	1.415	1.627	1.881	2.177	2.516	2.898	3.327	3.801	4.321
325	0.977	0.982	0.989	1.007	1.043	1.120	1.242	1.414	1.626	1.879	2.176	2.515	2.897	3.326	3.800	4.320
350	0.973	0.980	0.987	1.004	1.039	1.117	1.240	1.413	1.625	1.878	2.175	2.514	2.896	3.325	3.799	4.319
400	0.969	0.977	0.985	1.002	1.037	1.115	1.238	1.412	1.624	1.877	2.174	2.513	2.895	3.324	3.798	4.318
450	0.966	0.975	0.983	1.000	1.035	1.114	1.237	1.411	1.623	1.876	2.173	2.512	2.894	3.323	3.797	4.317
500	0.960	0.970	0.981	0.999	1.033	1.112	1.235	1.410	1.622	1.875	2.172	2.511	2.893	3.322	3.796	4.316

¹T.E.D.S. = thermoelectromotive force

intended for accurate measurements of temperatures should definitely be carried out in the A.U.S.R.I.M.

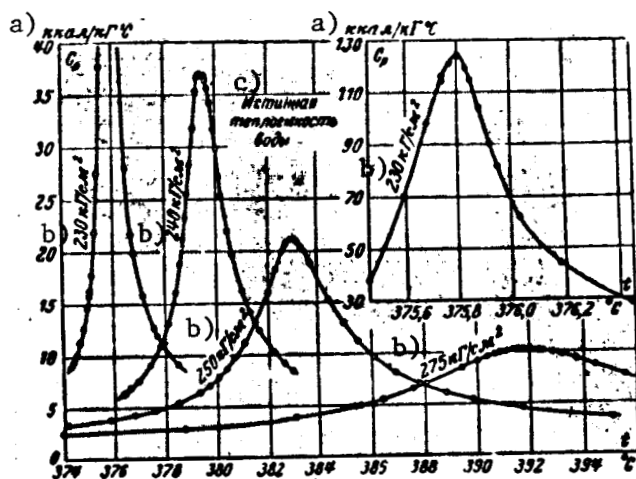


Fig. 1. New experimental data by the A.U.P.E.I. in the critical area.

Key: $a = \text{kcal/kg} \cdot ^\circ\text{C}$; $b = \text{kg/cm}^2$; $c = \text{True heat capacity of water.}$

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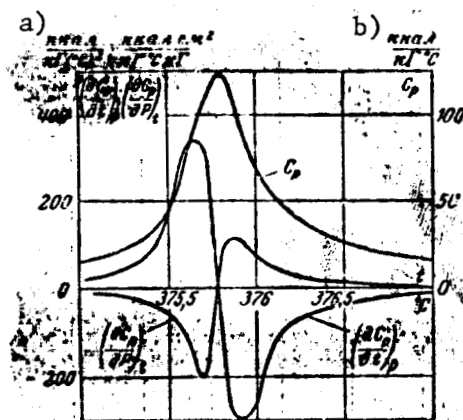


Fig. 2. Heat capacity c_p and derivatives $\left(\frac{\partial c_p}{\partial p}\right)_t$ and $\left(\frac{\partial c_p}{\partial t}\right)_p$ on isobar 230 kg/cm^2

Key: $a = \frac{\text{kcal}}{\text{kg}(\text{°C})^2}, \frac{\text{kcal} \cdot \text{cm}^2}{\text{kg}^2 \cdot \text{°C}}$

$b = \frac{\text{kcal}}{\text{kg}^\circ\text{C}}$

In order to compute the derivative $\left(\frac{\partial c_p}{\partial p}\right)_t$ it is necessary to pass from the experimental data in isobars to isotherms, thus making it rather difficult to compute the errors in proportion in the critical area. In this work, for the purpose of constructing isotherms at excess critical pressures, an interpolating method was used which was previously referred to in Reference 13 with the aid of the following diagram:

$$\frac{c_p}{c_{pm}} - (t - t_m),$$

where c_{pm} and t_m correspond to the value and temperature of the maximum c_p on the isobar.

For pressures up to the critical pressure, another variation of this method was used: interpolating with the aid of the diagram $\left(\frac{1}{c_p} - \frac{1}{c_{ps}}\right) - (t - t_s)$. The results of the computations of the derivatives $\left(\frac{\partial c_p}{\partial p}\right)_t$ and $\left(\frac{\partial c_p}{\partial t}\right)_p$ at isobar 230 and 240 kg/cm² are shown in Figures 2 and 3 where the isobars for c_p have also been shown for purposes of clarity. The lines of maxima c_p are close to one another at the isobars and isotherms in the critical area and therefore derivative $\left(\frac{\partial c_p}{\partial p}\right)_t$ bisects the axis of the abscissa at a temperature which does not differ greatly from the temperatures of the maximum at a given isobar (t_m). Inasmuch as $\left(\frac{\partial c_p}{\partial p}\right)_t$ equals 0 when t equals t_m , the magnitude ΔC_p at the point of maximum c_p must be close to zero. Along both sides of t_m the derivatives pass through the extremums and thus the extremal magnitude $\left(\frac{\partial c_p}{\partial p}\right)_t$ to the left of t_m is about twice as great as to the right of it. At isobar 230 kg/cm² the interval of the

temperature between the extremums $\left(\frac{\partial c_p}{\partial t}\right)_p$ amounts in all to 0.3°C and for $\left(\frac{\partial c_p}{\partial p}\right)_t$ this interval is still smaller, about 0.2°C . In the entire area for which derivatives were determined, in the units of measurement selected by us (kg/cm^2 , $^\circ\text{C}$) $\left(\frac{\partial c_p}{\partial t}\right)_p$ was greater than $\left(\frac{\partial c_p}{\partial p}\right)_t$. At the extremum point to the left of t_m the magnitude $\frac{1}{c_p} \left(\frac{\partial c_p}{\partial p}\right)_t$ amounts to 200% and $\frac{1}{c_p} \left(\frac{\partial c_p}{\partial t}\right)_p$ amounts to 400%, i.e., the change in temperature of 1°C changes c_p four times. However, thanks to the fact that the extremums of the derivatives are rather "sharp," the impact of the errors in proportion to the results of the measurement only has an effect in narrow temperature intervals on both sides of the maximum: for instance on isobar $230 \text{ kg}/\text{cm}^2$ the derivative $\left(\frac{\partial c_p}{\partial t}\right)_p$ decreases tenfold at a temperature which exceeds t_m by 0.9°C in all.

Figure 4 shows the sum error for circumcritical isobars 225, 230 and $240 \text{ kg}/\text{cm}^2$. In computing Δc_p the magnitude of the error in measuring the pressure and the temperature consequently was equal to 0.02% and 0.03°C . As follows from Figure 4, at isobar $230 \text{ kg}/\text{cm}^2$ the magnitude Δc_p exceeds 10% only within the interval of expansion of 1°C and at isobar $240 \text{ kg}/\text{cm}^2$ the sum error does not exceed 5%. The error owing to the errors in proportion at the point $225 \text{ kg}/\text{cm}^2$, 375°C amounts to 3% in all. At all of the other points in Table 1, the effect of the errors in proportion is still smaller.

In analyzing the disparities between the data of various authors in the critical area, it must be kept in mind that in some works the effect of the

errors, in proportion, in the evaluation of the measurement accuracy was not at all taken into consideration (for example in Reference 14) or else it was considered only for those experimental points which are situated rather far from the critical area. This situation should be kept in mind particularly when comparing the results of the measurements in References 5 and 14, since the magnitude of the error, when considered proportionally, in Reference 14 is quite great and is sufficient enough to explain the disparities which were noted in Reference 5.

As was shown, the errors in proportion in the case of c_p measurements in the critical area are close to zero at the maximum points. For this reason, when comparing the results computed according to the equations of the positions together with the table of bases it is advisable to also use the values of c_p which have been determined according to experimental data at the maximum points of isobars $(c_p)_m^p$. The experimental data in Reference 5 make it possible to add to the information on the maxima of c_p which are given in Reference 13.

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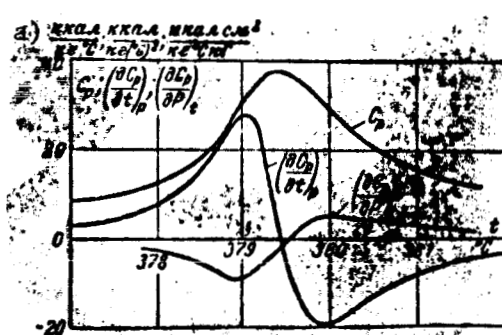


Fig. 3. Heat capacity c_p and derivatives $(\frac{\partial c_p}{\partial p})_t$ and $(\frac{\partial c_p}{\partial t})_p$ on isobar 240 kg/cm^2 .

Key: $a = \frac{\text{kcal}}{\text{kg}^\circ\text{C}} ; \frac{\text{kcal}}{\text{kg}(\text{°C})^2} ; \frac{\text{kcal} \cdot \text{cm}^2}{\text{kg}^2 \cdot \text{°C}}$

In Figure 5 there are shown for the experimentally obtained isobars in References 3 and 5 the deviations in the temperatures at the points of maxima (t_m) from the computed values found according to the formula of the straight line in coordinates $\lg p - \frac{1}{T}$:

$$\frac{1}{T} = \frac{1}{T_{cr}} - 0,487 \cdot 10^{-4} \lg \frac{p}{p_{cr}} \quad (2)$$

In the same figure the dotted line represents the deviations for the portion of the saturation curve bordering the critical point. According to the data of the A.U.P.E.I., the value of the derivative along curve $(c_p)_m^p$ in the critical area amounts to $2.62 \pm 0.07 \text{ kg/cm}^2 \cdot ^\circ\text{C}$ (which is a bit less than the value of the derivative along the saturation curve at the same point which, according to the data by Osborne, et al., equals $2.728 \text{ kg/cm}^2 \cdot ^\circ\text{C}$). For a smooth conjugation (without breaks) of the curve of the maxima with the saturation curve, it would suffice in Figure 5 to change the value of t_{cr} by several hundreds of degrees. The findings according to Formula 2 and the correction curve (Figure 5) of value t_m are given in Table 2.

Table 2. Maxima of heat capacity c_p on isobars

a) p , кг/см ²	t , °C	b) c_p , ккал/кг · °C	c) p , кг/см ²	t , °C	d) c_p , ккал/кг · °C
240	375.82	122.5	325	408.01	5.239
245	377.60	57.5	350	418.48	4.300
249	379.41	37.0	375	422.68	3.693
250	380.32	26.0	400	429.37	3.261
255	382.84	21.1	450	441.94	2.699
260	385.00	14.74	500	453.30	2.346
270	390.00	11.58	600	473.3	1.928
275	393.33	10.23	700	490.3	1.687
280	395.60	9.302	800	504.9	1.525
290	398.96	7.831	900	517.6	1.418
300	400.15	5.663	1000	528.6	1.385

Key: a) = p ,
кг/см² ; b) = c_p ,
ккал/кг · °C ; c) = p ,
кг/см² ; d) = c_p ,
ккал/кг · °C

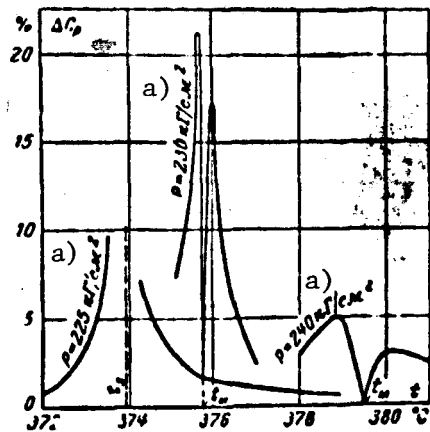


Fig. 4. Sum error of proportion for the new experimental data of the A.U.P.E.I. in the critical area.

Key: a) = kg/cm^2

The slight difference between these values and the values in Reference 13 is explained by the fact that the utilization of new data in the pressure interval 230 - 275 kg/cm^2 entailed a change in the form of the correction curve for higher pressures. In addition to this, value t_m at isobar 350 kg/cm^2 was rendered somewhat more accurately.

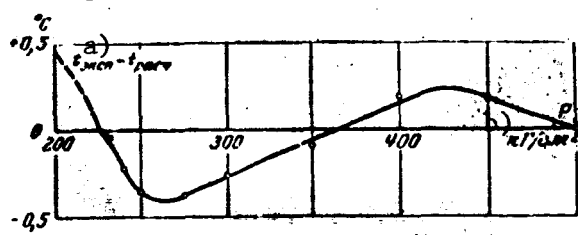


Fig. 5. Correction curve to Equation (2).

Key: a) = $t_{\text{extr}} - t_{\text{computed}}$; b) = kg/cm^2

It was shown in Reference 13 that at a pressure interval of 300 - 500 kg/cm^2 the linear dependence $\frac{1}{x}$ of p_m discovered by D. L. Timrot was not fulfilled at pressures up to 300 kg/cm^2 where

$$x = (c_p)_m^p - c_{p0}$$

New experimental data (Reference 5) showed that the values $(c_p)_m^p$ for isobars 250, 275 and 300 kg/cm² can be described, to a good degree of approximation, as a linear dependence if, instead of a critical pressure $p_{cr.} = 225.65$ kg/cm², there is used a somewhat fictitious value 227.620 kg/cm²:

$$\frac{1}{x} = \frac{p_m - 227.620}{461.51} \quad (3)$$

The experimental values in the diagram of $\frac{1}{x} - p$ at pressures below 250 kg/cm² deviate upwards from the computed values and at pressures above 300 kg/cm² they deviate downwards; for isobars 240 and 350 kg/cm² these deviations are not very large (Figure 6). At pressures which are approximately equal to 275 kg/cm² the dependence $\frac{1}{x} = f(p)$ has an inflection, this also making it possible to describe the portion bordering the inflation as a linear dependence $\frac{1}{x}$ of p_m , discovered by Timrot. The experimental values $(c_p)_m^p$ at low pressures agree satisfactorily with the critical pressure for which $\frac{1}{x} = 0$ (Figure 6).

An interpolation equation for $(c_p)_m^p$ can be obtained by adding to equation 3 an additional member, taking into account the deviation from the linear dependence at pressures bordering the critical pressure:

$$\Delta p = p_m - p_{cr} \quad (4)$$

Table 2 gives the values of $(c_p)_m^p$ which have been computed according to this equation for pressures up to 300 kg/cm² inclusive. At higher pressures the values of c_p at the maxima points on the isobars were calculated

according to Equation (5) (Reference 13) which, at pressures of 310 kg/cm², agree satisfactorily with Equation (4) for both the magnitude of $(c_p)_m^p$ itself and for the value of the derivative

$$\frac{1}{x} = 0,1567 + 1,521 \lg \frac{p}{300} + 0,975 \left(\lg \frac{p}{300} \right)^2. \quad (5)$$

In the work in Reference 8, it was shown that Equation (5), drawn up according to the experimental data of the A.U.P.E.I. for pressures up to 500 kg/cm², can also be used for higher pressures, since the value $(c_p)_m^p$ computed according to this formula agrees well with the results of extrapolation by the graphic method in special coordinates.

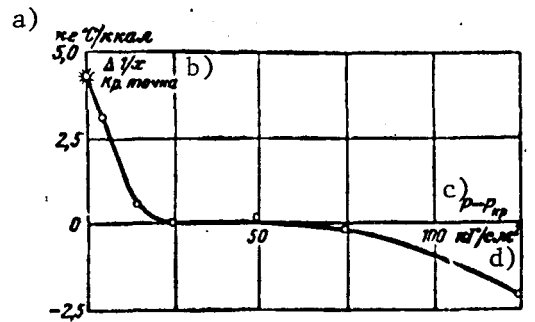


Fig. 6. Deviations of the experimental values of $(c_p)_m^p$ from the values computed according to Equation (3).

Key: a) = kg°C/kcal; b) = critical point; c) = p/p_{cp} ;
d) = kg/cm²

In the area of extrapolation, Equation (5) also agrees well with Equation (6):

$$x = \frac{1,9455}{p/p_{cp} - 1} + 0,244, \quad (6)$$

which describes the experimental values of $(c_p)_m^p$ at pressures of

400 - 500 kg/cm² (Reference 13) and agrees in form with the dependence discovered by Kaganer for some other substances (Reference 15). A similar expression can be used for extrapolating the dependence

$$x = f(t_m); \quad x = \frac{167,8}{t_m - t_n} - 0,275. \quad (7)$$

This equation describes the experimental data in the same range as in Equation (6). Removing x from Equation (6) and Equation (7) we obtain an equation for extrapolating the lines of maxima c_p at isobars in the $p - t$ diagram:

$$t - t_{np} = \frac{167,8p - 3,786 \cdot 10^4}{0,519p + 321,9}. \quad (8)$$

This equation is a hyperbola having an asymptote at $T = 970.5$ °K. In this way, the extrapolation method referred to leads to the same result as was obtained in Reference 15, at high pressures the line of maxima $(c_p)_m^p$ approaches the isotherm. The reduced temperature of this isotherm for water according to Equation (8) is greater than in the case of a number of other substances, according to the data in Reference 15:

$$\frac{T}{T_{cr.}} \approx 1.5 \text{ in lieu of } 1.2$$

The values of t_m brought forth in Table 2 for pressures exceeding 500 kg/cm² are computed according to Equation (8). The deviations from the results in Reference 8 amount to 4 - 8 °C.

Table 3 gives the enthalpy values of water and steam which have been computed by integrating the data of the A.U.P.E.I. for c_p given in References 1 - 6 and also the data in Reference 10. The integration was carried out according to isobars, beginning with the 0 °C isotherm where, as the

beginning of the computation the enthalpy taken was computed according to the formula $i = 2.41 \cdot 10^{-2} p - 2 \cdot 10^{-6} p^2$ (Reference 11).

Table 3. Enthalpy of water and steam $i, \text{kcal/kg}$

$t, ^\circ\text{C}$ $p, \text{kg/cm}^2$	0	50	100	150	200	250	300	350	375	400	425	450	475	500	550	600
50	1.20	50.99	100.93	151.62	203.88	259.28	691.5	733.9	749.3	763.9	778.1	792.2	806.2	820.2	844.2	876.2
75	1.80	51.50	101.38	152.00	204.16	259.30	674.2	718.5	736.6	753.0	768.6	783.8	798.7	813.5	842.8	871.7
100	2.39	52.02	101.84	152.40	204.42	259.34	320.86	700.3	722.3	741.1	758.5	775.1	791.0	806.6	837.3	867.2
125	2.98	52.53	102.28	152.78	204.70	259.36	320.18	678.0	705.8	728.2	747.8	765.9	781.0	799.6	831.7	862.5
150	3.57	53.04	102.74	153.15	204.97	259.40	319.58	646.2	687.0	713.7	736.3	758.3	774.7	792.3	825.9	857.8
175	4.16	53.55	103.20	153.52	205.24	259.46	319.05	397.84	664.0	697.2	723.3	745.7	765.9	784.8	819.8	852.6
200	4.74	54.06	103.64	153.91	205.52	259.51	318.60	391.71	629.4	677.4	708.8	734.1	756.2	776.6	813.4	847.4
225	5.31	54.56	104.10	154.30	205.80	259.62	318.20	390.66	558.3	653.4	691.2	721.6	745.8	768.1	806.9	842.1
250	5.90	55.07	104.54	154.67	206.08	251.73	317.86	388.25	444.4	623.2	673.8	707.9	734.9	758.8	800.0	836.7
275	6.47	55.57	105.00	155.04	206.37	259.84	317.55	386.30	435.0	581.5	653.1	691.2	723.5	748.3	791.0	831.8
300	7.05	56.08	105.45	155.45	206.66	259.95	317.29	384.62	429.3	575.4	630.1	677.6	711.4	738.4	785.7	825.2
350	8.19	57.08	106.34	156.21	207.23	260.19	316.87	381.84	421.9	478.1	574.8	642.9	685.8	718.5	770.2	813.9
400	9.32	58.07	107.23	156.98	207.81	260.49	316.57	379.61	416.7	462.8	529.8	605.4	658.2	698.8	754.9	801.1
450	10.44	59.05	108.10	157.74	208.41	260.77	316.29	377.83	413.1	454.3	516.8	572.4	630.8	674.8	739.6	789.8
500	11.55	60.06	109.01	158.53	209.03	261.12	316.10	376.47	410.3	448.4	493.9	548.9	605.8	653.7	724.8	778.1

REFERENCES

1. Sirota, A. M. and D. L. Timrot. "Teploenergetika" (Power Engineering), No. 7, 1956.
2. Sirota, A. M. "Teploenergetika" (Power Engineering), No. 7, 1958.
3. Sirota, A. M. and B. K. Mal'tsev. "Teploenergetika" (Power Engineering), No. 9, 1959.
4. Sirota, A. M. and B. K. Mal'tsev. "Teploenergetika" (Power Engineering), No. 10, 1960. /69
5. Sirota, A. M. and B. K. Mal'tsev. "Teploenergetika" (Power Engineering), No. 1, 1962.
6. Sirota, A. M. and B. K. Mal'tsev. "Teploenergetika" (Power Engineering), No. 7, 1962.
7. Sheyndlin, A. E., E. E. Spil'rayn, and V. V. Sychev. "Teploenergetika" (Power Engineering), No. 12, 1959.
8. Bukalovich, M. P., V. B. Dzampov, D. S. Rasskazov, and S. A. Remizov. "Teploenergetika" (Power Engineering), No. 12, 1961.
9. "Thermophysical Properties of Substances" (Teplofizicheskiye Svoystva Veshchestv). Handbook. Gosenergoizdatel'stvo (Government Power Engineering Publishing House), 1956.
10. Koch, W. Research in the Areas of the Engineering Sciences (Forschung auf den Gebiete des Ingenieurwesens). Vol. 3, No. 1, 1932.
11. Sirota, A. M. and P. E. Belyakova. "Teploenergetika" (Power Engineering), No. 10, 1959.
12. Rivkin, S. L. and T. S. Akhundov. "Teploenergetika" (Power Engineering), No. 1, 1962.
13. Sirota, A. M., B. K. Mal'tsev, and P. E. Belyakova. "Teploenergetika" (Power Engineering), No. 7, 1960.

14. Timrot, D. L., N. B. Vargaftik and S. L. Rivkin. Izvestiya VTI (Reports of the A.U.P.E.I.), No. 4, 1958.
15. Kaganer, M. G. ZH F X Zhurnal Fizicheskoi Khimii (Journal of Physical Chemistry), Vol. 32, 1958.

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